IMPROVEMENT OF LASER WIRE MONITOR AT NEWSUBARU

S.Hashimoto#
Laboratory of Advanced Science and Technology for Industry, University of Hyogo
NewSUBARU, 1-1-2 Koto, Kamigori, Ako, Hyogo, 678-1205 JAPAN

Abstract

The laser wire monitor developed in NewSUBARU can measure the vertical beam size accurately in decay mode. In top-up mode, however, spike noises in the γ measurement are observed in synchronism with beam injection and impair the measurement accuracy. To resolve this problem we have made a masking circuit, which masks the γ signal just after beam injection by stopping the counter for several ms. By setting mask width comparable to damping time of betatron oscillation, the spike noise disappears and the vertical beam size can be accurately measured even in top-up operation. Measured beam size and emittance are in good agreement with calculations. In the laser wire monitor, Bremsstrahlung is the origin of both background noise and spike noise. We found that, in background noise, γ yield by the collision of lost electrons with vacuum chamber is comparable to that by the collision of circulating electrons with residual gas molecules. On the other hand, in spike noise, γ yield is mainly from the former.

INTRODUCTION

It is important to non-destructively measure transverse profiles of an electron beam stored in synchrotron light sources for their stable operation. One of these measurements is laser wire monitor [1,2,3], which can measure horizontal and/or vertical beam size by measuring gamma photons generated by Compton back scattering. The measurement principle of the monitor is very simple. A thin laser wire is scanned transverse to an electron beam. When laser photons collide with beam electrons, high-energy gamma photons are generated. Assuming that the transverse distributions of both the laser beam and the electron beam are Gaussian, the distribution of the measured gamma photons should be also Gaussian distribution, $\sigma_\gamma^2 = \sigma_e^2 + \sigma_L^2$, where σ_γ, σ_e, σ_L are standard deviation of the transverse distributions of the gamma photons, the electron beam and the laser beam, respectively. Therefore by measuring the distribution of gamma photons with a detector, σ_e can be precisely measured.

We have developed a compact laser wire monitor system suitable for small synchrotron radiation source such as NewSUBARU, and succeeded in the measurement of small vertical beam size [4]. In the top-up operation, however, undesirable spike noises were observed in synchronism with beam injection as shown in Fig. 1, which shows time chart of the stored beam current and the number of gamma photons per second. These gamma photons are generated due to Bremsstrahlung, because laser power is stopped. And this noise degraded the accuracy of the measurement as shown in Fig. 2.

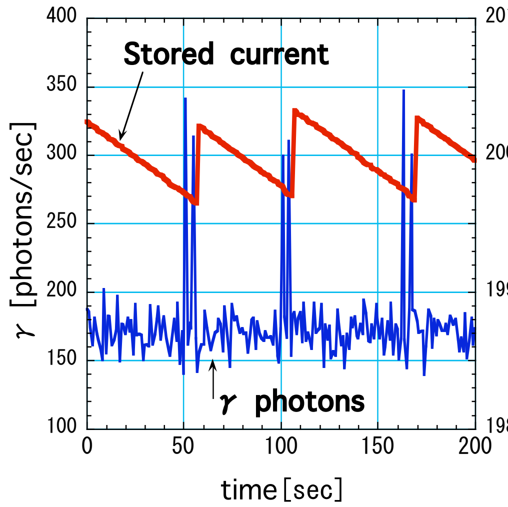

Fig. 1. Time chart of stored current and gamma photons in the top-up operation. Spike noise in γ measurement is observed in synchronism with beam injection.

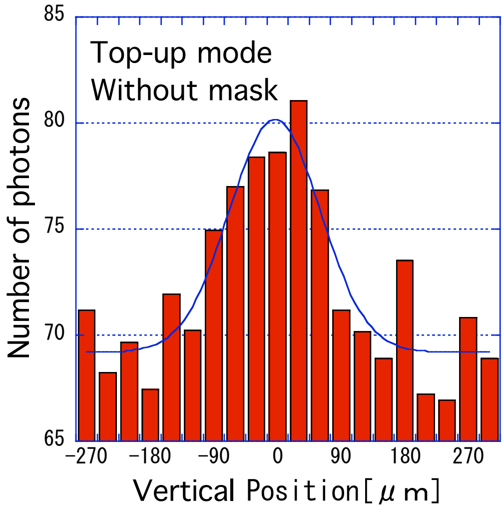

Fig. 2. Distribution of gamma photons by the laser wire monitor in top-up operation (Without Mask).

#hashi@lasti.u-hyogo.ac.jp

MASEREMENT IN TOP-UP MODE WITH MASKING NOISE SIGNAL

Because the ring can be operated in top-up mode to keep the stored current constant, the monitor is preferred to measure the beam size accurately during a beam injection. To reduce these spike noises we masked the gamma signal just after beam injection by stopping the counter for several ms. Figure 3 shows the dependence of mask width on the noise strength, which is defined as the height of spike noise from the average value in Fig.1. The noise strength decreases with an increase in mask width and diminishes at 20 ms, which almost corresponds to the damping time of betatron oscillation. This result indicates that an extremely small part of a circulating beam is lost just after beam injection, when the amplitude of horizontal betatron oscillation is relatively large.

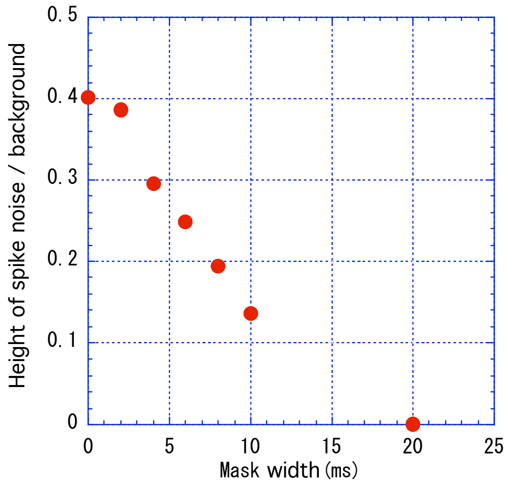

Fig. 3. Strength of spike noise vs. mask width.

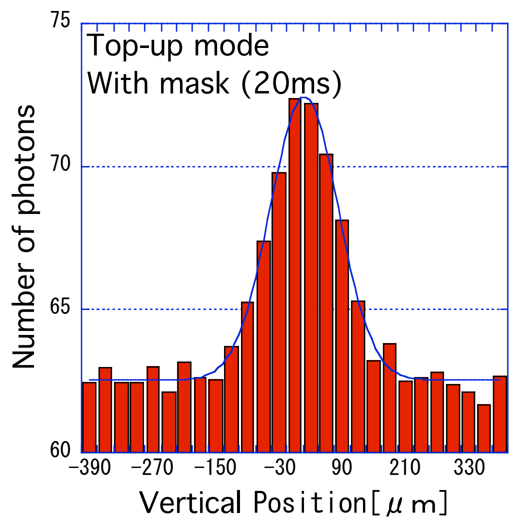

Fig. 4. Distribution of gamma photons by the laser wire monitor in top-up operation (With mask of 20ms).

The vertical beam size measurement with mask in the top-up operation is shown in Fig. 4, where the effect of spike noise is disappeared. Appling Gauss fitting to the measured data, we can find that σ_γ is 74 micron. Assuming that σ_L is 14 micron, it is found that σ_e is 69 micron. The vertical betatron function β_y at the interaction point calculated by MAD is 10 m. Using $\sigma_e = \sqrt{\varepsilon_y \beta_y}$, the vertical emittance can be estimated as ε_y=4.9e-10 m-rad, which corresponds to 1.2% coupling.

ORIGIN OF BREMSSTRAHLUNG GAMMA PHOTONS

Without laser input, measured gamma photons are generated by Bremsstrahlung, i.e., electromagnetic radiation produced by the deceleration of a high-energy electron when deflected by an atomic nucleus. In the laser wire monitor, gamma photons produced by Bremsstrahlung are a cause of both background noise and spike noise in synchronism with beam injection. Then what is an origin of Bremsstrahlung gamma ? Dose all gamma yield come form collision with residual gas molecules ?

Measured γ yield Y can be expressed as follows,

$$Y = Y_{loss} + Y_{gas}$$

where Y_{loss} denotes the yield generated when an electron lost from a bunch by gas scattering or Touschek effect collides with the surroundings such as vacuum chamber, absorber, and so on. And Y_{gas} denotes the yield due to collisions of circulating electrons with molecules of residual gas in vacuum chamber. Assuming that Y_{loss} is proportional to the number of electrons lost from bunched beams per unit time, it is written as

$$Y_{loss} \propto \left| \frac{dI}{dt} \right| \propto \frac{I}{\tau},$$

where I is the beam current and τ the beam lifetime. As Y_{gas} is proportional to the beam current and the density of residual gas molecules d_g, we have

$$Y_{gas} \propto I \cdot d_g \propto I \cdot \left(p_0 + \frac{dP}{dI} \cdot I \right),$$

where p_0 the vacuum pressure at off beam, dP/dI the pressure increase per stored current. Thus the total yield of Bremsstrahlung gamma Y can be expressed as a function of I and τ by the following equation,

$$Y = a \cdot \frac{I}{\tau} + b \cdot I^2 + c \cdot I,$$

where a, b, c are constants.

To estimate the origin of the background noise in the laser wire monitor, we have measured gamma yield at various beam current as functions of I/τ and $1/\tau$ as shown in Fig. 5 and 6. Fitting the above equation to these data, we can express the yield of background noise as

$$Y_{BG} \approx 34 \cdot \frac{I}{\tau} + 0.022 \cdot I^2 + 5.5 \cdot I.$$

We find that the first term is comparable to the sum of the second and third terms. Thus the origin of the background noise in the laser wire monitor is in halves of gas scattering and collision of lost electron with chamber.

In the case of spike noise, on the other hand, the yield can be expressed as

$$Y_{spike} \approx 49 \cdot \frac{I}{\tau} + 0.031 \cdot I^2 + 19 \cdot I.$$

In the above expression the first term is greater than the other terms. The fact shows that the spike noise comes from mainly the small amount of beam loss just after injection, which corresponds to dependency of spike noise to mask width shown in Fig. 3.

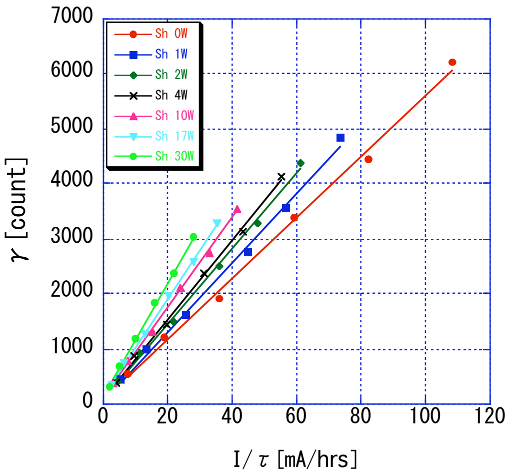

Fig. 5. Gamma photons vs. I/tau.

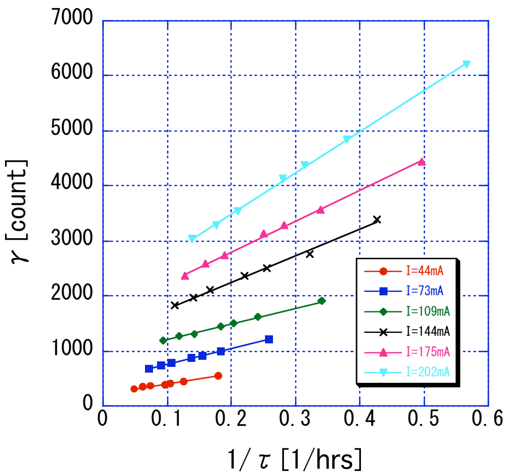

Fig. 6. Gamma photons vs. inverse lifetime.

SUMMARY

We have developed the compact laser wire monitor to measure small electron beam size in NewSUBARU. The monitor can measure the vertical beam size accurately in decay mode. In top-up mode, however, spike noise observed in synchronism with beam injection impaired the measurement accuracy. In order to resolve this problem, we have made a masking circuit, which masks the gamma signal just after beam injection by stopping the counter for several ms. By setting mask width comparable to the damping time of betatron oscillation, spike noise disappeared and the vertical beam size can be accurately measured even in top-up operation. Measured beam size and emittance are in good agreement with calculations.

In the laser wire monitor, Bremsstrahlung is the origin of both background noise and spike noise in synchronism with beam injection. We found that, in background noise, the gamma yield by the collision of lost electron with vacuum chamber is comparable to that by the collision of a circulating electron with residual gas molecular. On the other hand, in spike noise, the yield is mainly from the collision of lost electron with vacuum chamber.

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